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Utilization of Lightweight Materials Made from Coal Gasification Slags

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U.S. Department of Energy
Office of Fossil Energy
Federal Energy Technology Center
Morgantown Site
P.O. Box 880
Morgantown, West Virginia 26507-0880

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By
Praxis Engineers, Inc.
852 North Hillview Drive
Milpitas, California 95035

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1.0 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1.1 Introduction

Integrated-gasification combined-cycle (IGCC) technology is an emerging technology that utilizes coal for power generation and production of chemical feedstocks. However, the process generates large amounts of solid waste, consisting of vitrified ash (slag) and some unconverted carbon. In previous projects, Praxis investigated the utilization of "as-generated" slags for a wide variety of applications in road construction, cement and concrete production, agricultural applications, and as a landfill material. From these studies, we found that it would be extremely difficult for "as-generated" slag to find large-scale acceptance in the marketplace even at no cost because the materials it could replace were abundantly available at very low cost. It was further determined that the unconverted carbon, or char, in the slag is detrimental to its utilization as sand or fine aggregate. It became apparent that a more promising approach would be to develop a variety of value-added products from slag that meet specific industry requirements. This approach was made feasible by the discovery that slag undergoes expansion and forms a lightweight material when subjected to controlled heating in a kiln at temperatures between 1400 and 1700°F. These results indicated the potential for using expanded slag as a substitute for conventional lightweight aggregates (LWA). The technology to produce lightweight and ultra-lightweight aggregates (ULWA) from slag was subsequently developed by Praxis with funding from the Electric Power Research Institute (EPRI), Illinois Clean Coal Institute (ICCI), and internal resources.

The major objectives of the subject project are to demonstrate the technical and economic viability of commercial production of LWA and ULWA from slag and to test the suitability of these aggregates for various applications. The project goals are to be accomplished in two phases: Phase I, comprising the production of LWA and ULWA from slag at the large pilot-scale, and Phase II, which involves commercial evaluation of these aggregates in a number of applications. Phase I was due to end on 14 December 1995 but has been extended to 14 June 1996 due to the unexpectedly long time it took for collection of slag samples. The scheduled completion date for Phase II has therefore been extended to 14 September 1997.

Primary funding for the project is provided by DOE's Morgantown Energy Technology center (METC) with significant cost sharing by Electric Power Research Institute (EPRI) and Illinois Clean Coal Institute (ICCI).

1.2 Scope of Work

The project scope consists of collecting a 20-ton sample of slag (primary slag), processing it for char removal, and subjecting it to pyroprocessing to produce expanded slag aggregates of various size gradations and unit weights, ranging from 12 to 50 lb/ft^3. A second smaller slag sample will be used for confirmatory testing. The expanded slag aggregates will then be tested for their suitability in manufacturing precast concrete products (e.g., masonry blocks and roof tiles) and insulating concrete, first at the laboratory scale and subsequently in commercial manufacturing plants. These products will be evaluated using ASTM and industry test methods. Technical data generated during production and testing of the products will be used to assess the overall technical viability of expanded slag production.

In addition, a market assessment will be made based on an evaluation of both the expanded slag aggregates and the final products, and market prices for these products will be established in order to assess the economic viability of these utilization technologies. Relevant cost data for physical and pyroprocessing of slag to produce expanded slag aggregates will be gathered for comparison with (i) the management and disposal costs for slag or similar wastes and (ii) production costs for conventional materials which the slag aggregates would replace. This will form the basis for an overall economic evaluation of expanded slag utilization technologies.

1.3 Task Description

A summary of the tasks to be performed in Phase I is given below:

Task 1.1 **Laboratory and Economic Analysis Plan Development**: Development of a detailed work plan for Phase I and an outline of the Phase II work.

Task 1.2 **Production of Lightweight Aggregates from Slag**: Selection and procurement of project slag samples, slag preparation including screening and char removal, and slag expansion in a direct-fired kiln and fluid bed expander. Preliminary laboratory-scale studies will be conducted before bulk samples of expanded slag are collected for processing. The char recovered from the slag preparation operation will be evaluated for use as a kiln fuel and gasifier feed. Environmental data will also be collected during preparation and expansion of slag.

Task 1.3 **Data Analysis of Slag Preparation and Expansion**: Analysis and interpretation of project data, including development of material and energy balances for slag processing and product evaluation.

Task 1.4 **Economic Analysis of Expanded Slag Production**: Economic analysis of the utilization of expanded slag by determining production costs for slag-based LWAs and ULWAs. An estimated market value will be established for the various expanded slag products. Expanded slag production costs will be compared with the costs of disposal and management of slag as a solid waste.

Task 1.5 **Topical and Other Reports**: Preparation and delivery of topical, financial status, and technical progress reports in accordance with the Statement of Work.

The Phase II effort will focus on field studies conducted on expanded slag aggregates to test their performance as substitutes for conventional materials in various applications, including masonry blocks, roof tiles, insulating concrete, and insulation fill. Mix designs will be formulated and tested by refining the material proportions used in previous work. Commercial manufacturing practices, standards, and equipment will be used for this work. New applications may also be identified during the course of this work. The economic analyses conducted in Phase I will be further refined in Phase II using the new data.

1.4 Scope of this Document

This is the sixth quarterly report and summarizes the work undertaken during the performance period between 1 December 1995 and 29 February 1996.

2.0 SUMMARY OF WORK DONE DURING THIS REPORTING PERIOD

2.1 Summary of Major Accomplishments

The following was accomplished during the current reporting period:

1. The Project Work Plan was changed, with the approval of the DOE COTR, to allow use of a fluid bed expander instead of an indirect-fired kiln to produce expanded slag aggregates (SLA) with unit weights in the range categorized as ultra-lightweight aggregates (ULWA). This method offers the potential for producing ULWAs in a more energy-efficient manner than the indirect-fired kiln. The fluid bed expander can also be used to produce LWAs by operating it at a lower temperature. A test plan for conducting pilot test runs using the expander was prepared and is being reviewed by Fuller. The test work is scheduled to be conducted in March 1996.

2. Characterization of expanded slag (size distribution, unit weight, moisture absorption, and RCRA leachability) is in progress.

3. Laboratory-scale applications-oriented testing of SLA as a substitute for LWA and ULWA was also started in the current reporting period. This work involves preparation of SLA samples to meet the particle size and unit weight requirements of various applications and entails grinding and blending SLA products of different sizes and unit weights. The target applications are listed below:

    - Structural concrete (three SLA products)
    - Lightweight concrete masonry unit (lightweight blocks, 2-3 blends)
    - Insulating concrete
    - Lightweight roof tile aggregate (three SLA products)
    - Loose fill insulation
    - Horticultural application.

    Procedures describing key industrial practices and ASTM standards were developed and provided to selected test laboratories who will be testing SLA as a substitute for conventional LWAs and ULWAs.

2.2 Chronological Listing of Significant Events in This Quarter

The following significant events occurred during the current reporting period:

Date	Description
12/10/95	Test planning for slag lightweight aggregate (SLA) laboratory evaluation continued
12/12/95	SLA product characterization initiated
1/20/96	Laboratories for testing of SLA products identified
2/16/96	Test plan for second batch of fluid bed expander testing at Fuller completed
2 /21/96	SLA product samples prepared for laboratory evaluation

3.0 TO DATE ACCOMPLISHMENTS

This section summarizes the work completed to date in the first six quarters of the project:

Date	Accomplishments
10/24/1994	"Draft Laboratory and Economic Analysis Plan" prepared and submitted
11/07/1994	Advance sample of primary project slag collected for testing for char removal
11/18/94	Slag processing for char removal completed successfully on the advance sample and prepared slag sent to Fuller and Silbrico for expansion testing
12/02/94	Final "Laboratory and Economic Analysis Plan" prepared and submitted
12/14/94	Testing of advance slag sample at Fuller and Silbrico indicates that it has excellent expansion properties
02/15/94	Evaluation of blendability of slag fines with an expansible clay initiated at Fuller
03/05/95	Decision made regarding primary and secondary project slag samples
04/15/95	Laboratory extrusion testing of the advance sample using an expansive clay binder completed at Fuller
05/21/95	Primary slag sample received at Penn State for preparation
05/30/95	Characterization of primary slag using samples from two drums completed
06/01/95	Pilot unit for char removal set up
06/21/95	Second slag sample tested and evaluated for expansion characteristics
06/30/95	Char removal operational problems solved and continuous slag processing started
08/20/95	Primary slag sample processing for char removal completed
08/31/95	Slag screening of primary slag at 10 mesh and 50 mesh started
9/10/95	Laboratory studies of slag expansion on the two slags completed
9/20/95	Laboratory testing of pelletized slag/clay blends started
10/15/95	1-ft and 3-ft diameter kilns commissioned for pilot testing
11/15/95	Pilot testing of Slag I in 3-ft dia. direct-fired kiln completed
11/16/95	Pilot testing of pelletized Slag I in 1-ft dia. direct-fired kiln completed
11/17/95	Pilot testing of Slag II in 1-ft dia. direct-fired kiln completed
12/10/95	Test planning for slag lightweight aggregate (SLA) laboratory evaluation continued
12/12/95	SLA product characterization initiated
1/20/96	Laboratories for testing of SLA products identified
2/16/96	Test plan for second batch of fluid bed expander testing at Fuller completed
2/21/96	SLA product samples prepared for laboratory evaluation

4.0 TECHNICAL PROGRESS REPORT

The major accomplishments during this reporting period were in the following areas:

- Laboratory evaluation and characterization of slag lightweight aggregate products
- Planning for pilot-scale fluid bed expander test work.

4.1 Fluid Bed Expander Pilot Test Program

A change order was obtained from DOE to allow use of a fluid bed expander for pilot-scale slag expansion instead of an indirect-fired kiln as originally planned. In the fluid bed expander, high-temperature combustion products are bubbled through a bed of the feed material without allowing direct contact between the feed and the flame. The fluidization velocity is controlled carefully to allow a carryover of the expanded material, thus preventing overheating and possible fusion of the material. The fluid bed method of slag expansion was selected as an alternative to the indirect firing method due to its greater energy efficiency. Preliminary tests conducted using a pilot-scale fluid bed expander for slag expansion were very successful. A test plan for pilot-scale testing using the expander was prepared. The objectives of the slag expansion test program are unchanged and are summarized below.

1. Demonstrate Slag Expansion in a Fluid Bed Expander

- Can the fluid bed expander be used to produce SLA products with unit weights spanning the entire targeted range (15-50 lb/ft^3)?
- Can the fluid bed expander be used for expansion of extruded slag/clay pellets?
- Demonstrate the suitability of the fluid bed expander using other slags.

2. Char Removal Needs and Char Utilization Potential

- Can the slag be expanded without processing for char removal?
- Can controlled quantities of char be introduced into the fluid bed expander to reduce fuel consumption?
- What is the impact of the carbon content of unprocessed (raw) extruded slag on expansion in a fluid bed expander and on the expanded product?

3. Gather Technical Data for Process Engineering Design

- Determine the feed rate, residence time, energy consumption, and other design data for commercial sizing of fluid bed expansion of slag.
- Determine a mass balance for fluid bed expander operation.

4.2 Pilot Test Runs for Fluid Bed Expander

In order to achieve the project objective of demonstrating the production of expanded slag at the pilot scale, a test matrix was developed for the fluid bed method of expansion to produce products with unit weights of 12-50 lb/ft^3. Table 1 lists the slag feed materials planned to be processed in the fluid bed expander. This plan will be reviewed with Fuller and finalized based on the availability of funds and ancillary equipment to prepare the feed and char. In order to provide a summary of SLA products produced in the project, the table includes products that were produced using a direct-fired kiln.

Table 1. SLA Products from Direct-Fired Kiln and Fluid Bed Expander

Slag/Size Tested	Direct-Fired Kiln Testing (Completed)		Fluid Bed Expander Testing (Proposed)	
	Unit Wt lb/ft^3	Quantity Produced[1] Drums	Unit Wt lb/ft^3	Feed Quantity Drums
Slag I: + 10M	30-55	19	**12-50**	**2**
Char injection	--	--	**30**	**1/2**
Slag I: 10 x 50M	35-55	16	**12-50**	**2**
Char injection	--	--	**30**	**1/2**
Extruded Slag/Clay				
80/20	30, 40, 60	16	**12-50**	**1/2**
50/50	20, 30, 35, 40	19	**12-50**	**1/2**
0/100	20, 30, 40	8 + 9	**12-50**	**1/2**
Char injection 50/50	--	--	**12-50**	**1/2**
Slag II (TVA): +10M[2]	20, 30, 40, 50	8+21	**12-50**	**1/2**
Extruded Slag II: -10M and granulated	--	--	**12-50**	**--**
Slag III: -10M[3]	--	--	**12-50**	**1/2**
Total drums				**8**
Feed rate, lb/hour				**50-100**

Explanations:

(1) The drums contain products from various time intervals and are not necessarily full.

(2) The +10M Slag II could be combined with the -10M, crushed, and extruded.

(3) Earlier tests with Slag III indicated potential fusion problems; lab work may be needed prior to pilot testing. A portion of the sample is at Praxis.

Since the design of the fluid bed expander provides better combustion control than a direct-fired kiln, sampling of the off-gas stream to determine SO_2, NO_x, CO, CO_2, and O_2 is not required.

4.3 Preparation of SLA Products for Laboratory Evaluation

Prior to using expanded slag products generated from the pilot plant in various end-use applications, they must be characterized and subjected to laboratory evaluation. In this reporting period, laboratory evaluation of expanded slag was initiated. Details are provided below.

1. Physical Characterization

Determinations were made of the particle size distribution, unit weight, and moisture adsorption of various SLA products generated using the direct-fired kiln.

2. Environmental Characterization (TCLP)

A sample of expanded slag was prepared to match the particle size distribution required for roof tiles and subjected to RCRA/TCLP testing in accordance with EPA SW-846. This application was selected because extensive size reduction of expanded aggregates is needed to meet the size requirements, thus potentially making it the most leachable SLA product. The results indicated that TCLP leachate heavy metals concentrations were considerably lower than the RCRA requirements.

3. Laboratory Evaluation of SLA

Laboratory-scale applications-oriented testing of SLA as a substitute for LWA and ULWA was started during this reporting period. This work involved preparation of SLA samples to meet the particle size and unit weight requirements of various applications, and entailed grinding and blending of SLA products of various sizes and unit weights. The specific applications are listed below:

- Structural concrete (three SLA products)
- Lightweight concrete masonry unit (lightweight blocks, 2-3 blends)
- Insulating concrete
- Lightweight roof tile aggregate (three SLA products)
- Loose fill insulation
- Horticultural application.

The specifications and tests planned are given in Table 2.

Table 2. Applications Tests and Expanded Slag Samples to be Used

	Aggregates		Expanded Slag Product Sample	
LWA Applications	**Target Size/Specifications**	**Target Unit Wt lb/ft^3**	**Slag**	**Slag/Clay Pellets**
Structural concrete	(i) 3/4" coarse LWA, ASTM C330 (ii) 3/8" combined LWA, ASTM C330 (iii) 3/4" pilot plant LWA	50 50 50	-- 1/4" x 50M --	50/50 -- 0/100
CMU concrete	Fine (-4M) LWA	50	1/4" x 50M	50/50
Roof tile concrete	Two SLA samples of fine (-6M) LWA (size gradation given by manufacturer) and two control samples	40	Crushed 1/4" x 50M	50/50 (Crushed)
ULWA Applications				
Insulating concrete	ASTM C332 Group II (45-90 lb/ft^3 concrete)			--
Loose fill insulation	ASTM C549	<12	10 x 50M	--
Horticulture	Expanded perlite size range	<12	10 x 50M	--

Procedures describing key industrial practices were developed and ASTM standards provided to various laboratories selected to test SLA as a substitute for conventional LWAs and ULWAs.

4.6 Conclusions and Recommendations

A pilot-scale test plan was prepared for production of expanded slag aggregates using a fluid bed expander. The objectives of the testing are summarized below:

- Demonstrate slag expansion in a fluid bed expander
- Determine the need for char removal and establish the potential for utilization of char
- Collect necessary technical data as part of developing the process engineering design.

In preparation for demonstration in various end-use applications, the SLA products were characterized. The results of RCRA testing indicated that the TCLP leachate heavy metals concentrations were considerably lower than RCRA requirements.

In addition, SLA product samples were prepared for laboratory evaluation. Laboratory testing in accordance with ASTM standards is currently in progress.

5.0 PLAN FOR THE NEXT QUARTER

The following activities are planned for the next quarter:

- Continue laboratory evaluation of expanded slag products from pilot-scale tests
- Conduct data analysis of the direct-fired kiln and fluid bed expansion methods of producing slag LWAs, including discrete-particle slag fractions and extruded slag/clay pellets
- Analyze data to establish mass and material balances for slag processing
- Continue work on economic analysis.